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Introduction
Computational science has become the third path to discovery in science and engineering along with theory and experimentation. It is central to research efforts in the biological and physical sciences, engineering, and medicine. Computational modeling is also crucial to the competitiveness of U.S. business and industry as a way of reducing product design, testing, production, and marketing costs in the face of international market competition. More recently, massive datasets has added to these demands on the workforce for people who understand the problems of storage, curation, and analysis of data not only from science and engineering endeavors but increasingly in the social sciences.

Although some strides have been made in integrating the competencies required in this field into the university curriculum, the pace of change has been slow resulting in a critical shortage of sufficiently qualified students at both the baccalaureate and graduate levels. The problems of integrating computational science into the curriculum are particularly acute on the campuses of minority serving institutions (MSIs). Heavy teaching loads and the lack of local resources combined with the limited number of faculty with computational science expertise significantly slows their efforts to implement curriculum changes.

The potential exists to take advantage of national efforts to integrate computational science into the curriculum and to apply distance learning technologies to form consortia with sufficient critical mass to support viable programs.

Computational Science Curriculum Workshop
NSF funded the Southeastern Universities Research Association (SURA) to convene a workshop for faculty and administrative leaders from MSIs who are committed to curricular reforms. The purpose of the workshop was to provide an opportunity for the participating institutions to accelerate implementation by tackling curriculum reform issues and planning in a focused uninterrupted environment with expert facilitation. The workshop builds on ongoing work of the NSF-funded Extreme Science and Engineering Discovery Environment (XSEDE) Under-Represented Community Engagement and Education programs where lessons learned and external evaluation informed the identification of the curriculum implementation issues at MSIs.

The workshop was co-facilitated by Linda Akli, SURA Assistant Director of Training Education and Outreach, and Steve Gordon, Ohio Supercomputer Center, Senior Education Specialist. Linda Akli leads the XSEDE Underrepresented Community Engagement Program and oversees the Minority Research Community and Minority Serving Institution Engagement programs. Dr. Gordon is the lead for the XSEDE education program where he works with universities nationwide to assist them in starting computational science education programs by providing program models, shared materials, and professional development activities for faculty.

Prerequisites for Participation
To ensure that the participating institutions are committed to add or deepen computational science in their curriculum, a letter of commitment from the relevant Deans and Provosts were required for participation. (See Appendix B for the list of Institutions and Appendix C for the institutional commitment letters.)
Fifteen institutions expressed interest. Only ten institutions participated in the workshop because of the requirement for a commitment letter. None of the participating institutions currently offer minors, certificates, or undergraduate programs in computational science and two offer PhD programs.

The pre-workshop assignment was sent to the participants asking them to analyze existing curriculum and expertise on campus in comparison to the model competencies using a template provided by the workshop facilitation team. The pre-workshop template and guidance is contained in Appendix D. Prior to the workshop, participants submitted their draft plans for review and feedback from the workshop facilitators. Many participants were able to incorporate the feedback and bring updated plans to the workshop. This process greatly enhanced the participants’ ability to benefit from attending the workshop and provided for “good” questions and rich discussion throughout the workshop.

**Workshop Agenda**

The final workshop agenda was designed to provide the participants with the tools and information necessary

1. to articulate a strong business case for making curriculum changes;
2. identify the resources and services that can be leveraged;
3. explore implementation collaborations;
4. to leave with draft plans ready for submission to for approval.

Primary priorities for university administration include enrollment (recruitment of new students and retention of current students), the employability of their graduates, and matriculation into graduate and professional programs. The industry presentations provided participants with a strong sense of the market for graduates with computational science skills. Nathan W. Klingbeil, of Wright State University reviewed his program for engineering mathematics as a way of retaining larger numbers of students in technical fields (see [http://cecs.wright.edu/community/engmath](http://cecs.wright.edu/community/engmath)). The outcomes from his program provided a strong business case for implementing curriculum changes. In particular, Dr. Klingbeil quantified the increase in tuition income resulting from retention of engineering students due to the mathematics curriculum changes. Workshop participants indicated that the same issues with using applied mathematics in science and engineering are important at their institutions and several indicated they would consider a similar curriculum change.

During the workshop, the participants were partnered for work sessions based on their goals, environments, and potential for collaboration. During the work group sessions, the participants shared their plans, provided feedback, and shared ideas on how to tackle some of the implementation issues. The participants chose to stay in the same work groups throughout the workshop. The work groups were as follows:

1. Clark Atlanta University, Morehouse College, and Spelman College
2. Florida A&M and Southern A&M, and New Mexico State
3. North Carolina A&T and University of Texas at El Paso
4. Navajo Technical University and Philander Smith College
Outcomes

Each institution created a draft plan and received feedback prior to the workshop with several using the pre-workshop feedback to do additional iterations of their plans. At the end of the workshop, each set of institutional participants left the workshop with an updated plan.

Table 1: Plan Summary Table

<table>
<thead>
<tr>
<th>Institution</th>
<th>Program Type</th>
<th>Implementation Strategy</th>
<th>Departments Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAU</td>
<td>Minor</td>
<td>Incremental - Consortium w/Morehouse &amp; Spelman</td>
<td></td>
</tr>
<tr>
<td>FAMU</td>
<td>PhD</td>
<td>Incremental – Collaboration w/NMSU &amp; Southern</td>
<td>Physics, Computer Sci.</td>
</tr>
<tr>
<td>Morehouse</td>
<td>U Minor</td>
<td>Incremental - Consortium w/CAU &amp; Spelman</td>
<td>Social Sciences</td>
</tr>
<tr>
<td>Navajo Tech</td>
<td>BS Degree</td>
<td>To be Determined</td>
<td>To be Determined</td>
</tr>
<tr>
<td>NMSU</td>
<td>Minor</td>
<td>Incremental</td>
<td>Engineering</td>
</tr>
<tr>
<td>NCAT</td>
<td>Minor</td>
<td>Undergraduate– collaboration w/UTEP</td>
<td>STEM</td>
</tr>
<tr>
<td>PSU</td>
<td>Minor</td>
<td>Incremental</td>
<td>STEM</td>
</tr>
<tr>
<td>Southern</td>
<td>Minor</td>
<td>Incremental – Collaboration w/FAMU &amp; NMSU</td>
<td>Math, Computer Sci.</td>
</tr>
<tr>
<td>Spelman</td>
<td>Minor</td>
<td>Incremental - Consortium w/CAU &amp; Morehouse</td>
<td>Chemistry</td>
</tr>
<tr>
<td>UTEP</td>
<td>Minor</td>
<td>Undergraduate– collaboration w/NCAT</td>
<td>All Disciplines</td>
</tr>
</tbody>
</table>

Eight of the institutions are planning on implementing an undergraduate minor or certificate; one is developing an undergraduate degree program; and one is developing a PhD program. As a result of the workshop and to address the difficulties of implementing larger scale programs, several participants identified implementation of computational science in a department as the first step in incrementally building towards minors, certificates or degree programs and several potential collaborations emerged.

At the end of the workshop, the participants were asked to complete a post-workshop survey prior Twenty of the twenty-one participants completed the post-workshop survey, a copy of which is contained in Appendix E.

Next steps identified by survey respondents were obtained through three questions. Question 1 - “What would facilitate further adoption/implementation of computational science at your institution?” revealed that external consultation and review of the plan were the top requested supports identified followed by a campus workshop and additional training.

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Another off-site workshop</td>
<td>42.11%</td>
</tr>
<tr>
<td>A workshop on campus</td>
<td>36.84%</td>
</tr>
<tr>
<td>External consultation/facilitation</td>
<td>68.42%</td>
</tr>
<tr>
<td>External review of the curriculum plan/proposal</td>
<td>73.68%</td>
</tr>
<tr>
<td>Additional training for you or your colleagues and if so what topics</td>
<td>26.32%</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>31.58%</td>
</tr>
</tbody>
</table>

Total Respondents: 19
Question 2 - The responses to the training question “What specific workshop topics would facilitate further implementation/adoption of computational science at your institution?” were varied. The participants training needs aligned closely with the discipline that would be the first on campus to implement computational science. For example, if computer science was the lead then desired training was “Parallel Programming” whereas if it was chemistry the training identified was computational chemistry. Seventy-five percent did identify “Computational Thinking” and “Using HPC and Visualization Resources” as a training topic.

Question 3 - The question “What are your next steps to further computational science adoption/implementation at your institution?” was open text. The responses were as follows:

- The Clark Atlanta participants are going to meet with the Dean of Natural Sciences and Mathematics to get all departments (Math, Chemistry, Physics, Computer Science, Psychology and Biology) involved by contributing one course to the minor. Initial implementation will focus on creating a minor for STEM within 2 years.
- Participants from FAMU will finish course descriptions for courses in curriculum for a computational science minor and will provide a status update at the next college committee meeting.
- The Morehouse team will finalize the minor program and offer courses one at a time starting with the development of a model course.
- The Navajo Tech participants are going to hold meetings and seek advice from faculty members with expertise in different areas.
- Participants from New Mexico State University are going to file the paperwork seeking approval for the proposed minor program.
- The North Carolina A&T State University team will update the Chair and recommend adoption of a minor.
- Philander Smith College is going to improve their plan by taking inputs from this workshop. The objectives for each course will be added then discussed with respective department chairs and Dean.
- The Southern University team is in the process of revising their plan of action and meeting with stakeholders (1. the Vice Chancellor of Research and Strategic Initiatives, 2. the Provost, 3. the deans of our respective colleges (College of Sciences and Agriculture and College of Engineering and Computer Science), 4. Department chairpersons).
- The Spelman plan is to collaborate with faculty at CAU and Morehouse to develop a joint minor in computational science.
- UTEP is going to conduct meetings with stakeholders on campus.

Workshop Evaluation
Overall, the workshop participants found the workshop beneficial. The one participant who was less enthused about the workshop was a last minute substitution for someone who had an emergency and couldn’t attend. The participants from social sciences found the industry presentation discipline specific and targeted more towards computer science and engineering and less beneficial to them.
Question 4 - How was the pre-workshop assignment helpful?

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was unable to complete the pre-workshop assignment</td>
<td>10.00% 2</td>
</tr>
<tr>
<td>Obtained support from colleagues and/or administration</td>
<td>60.00% 12</td>
</tr>
<tr>
<td>Enabled me to identify ways consortia and collaborations can be leveraged</td>
<td>65.00% 13</td>
</tr>
<tr>
<td>Accelerated progress in my curriculum plan/proposal development</td>
<td>75.00% 15</td>
</tr>
</tbody>
</table>

Total Respondents: 20

The responses to this question confirms that the pre-workshop assignment and activities especially the interaction with colleagues and administration contributed to the success of the workshop, the rich discussion, and the participants’ ability to share insights with each other.

The following set of survey questions were to inform our understanding of whether the workshop format was appropriate, the workshop location convenient, and the curriculum resources and speakers presentations were of value.

Question 5 - To what extent do you agree with the following statements regarding your experience at this workshop?

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Strongly Disagree</th>
<th>N/A</th>
<th>Total</th>
<th>Average Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. I met others with whom I plan to continue networking after the workshop during the next year</td>
<td>90% 0% 5% 0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>4.75</td>
</tr>
<tr>
<td>1.2. The Industry Panel provided me with information to advocate for computational science at my institution</td>
<td>65% 5% 0% 20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>4.42</td>
</tr>
<tr>
<td>1.3. I found the curriculum resources provided prior to the workshop useful</td>
<td>85% 10% 0% 0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>4.70</td>
</tr>
<tr>
<td>1.4. I found the curriculum resources presented during the workshop useful</td>
<td>85% 10% 0% 0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>4.70</td>
</tr>
<tr>
<td>1.5. Working in group setting was useful for understanding implementation strategies</td>
<td>65% 30% 0% 0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>4.50</td>
</tr>
</tbody>
</table>
Sixteen participants provided additional comments at the end of their survey.

This was an excellent workshop. I learned more about activities, strategies and the current general status of comp. science at similar institutions across the southeast. Good discussions, very informative feedback from industry highlighting again how vital this initiative is for jobs and economy, and a sense that this is technically do-able but the struggle everywhere is with some administrators, some chairs and some faculty. And a confirmation that there are alternative pathways if necessary (e.g. engineering vs. sciences).

This workshop is an excellent starting point to start computational science program. I have learned a lot of knowledge which are required to start Computational Science program. Discussion by industry panel is a valuable addition to this workshop.

I am grateful for the opportunity and the space to meet with colleagues from fellow institutions to think through and plan a computational science program. I have been introduced to aspects of the process that I was not originally considering and received resources to assist in the development and implementation of the program.

It was a great workshop and very helpful for developing research and educational collaborations. It was well-organized with great accommodations. The presentations and discussions were extremely useful.

Thank you for a great workshop. It was very useful. I really like the idea of applying for NSF funding to form a virtual consortium that was proposed by Florida A&M University. It would be great to see it materialize.

It has been really helpful to hear about the ideas for computational science education from someone experienced like Dr. Gordon, from colleagues at other institutions, as well as the industry representatives. Thank you for organizing this!

Thank you Linda and Steve. This workshop was great because I was able to connect with colleagues who are interested in computational science. We are also planning to start a new collaboration to bring computational science minor on our campus.
I truly would like to thank SURA for the successful Workshop on Integrating Computational Science into the curriculum. The Workshop has provided me a lot of opportunities to collaborate more with Southern University and A&M College Computational Science Campus Champion, Dr. Rachel Vincent-Finley, professors and company representatives at the Workshop. A lot of thanks to Dr. Steve Gordon and Ms. Linda Akli for their professionalism, cooperation, intensive mentoring. We are looking forward to more collaborations and meetings with SURA.

The workshop was well-planned and a successful event that supported our efforts to implement Computational Thinking in STEM.

If a consortium for course sharing were developed, it seems UTEP could likely contribute fairly high-level coursework, but would benefit from contributions of others in introductory coursework for non-science majors, such as an Introduction to Computational Science, and elementary courses in Modeling or Data Visualization that could be accessible with a background that includes an Intro to Programming course and Calc I.

Conclusions

The survey data and draft plans provide insight into the benefit of the workshop and how the participating institutions are planning on proceeding. The primary outcomes of the workshop are:

1. Participants made significant progress on drafting plans and left the workshop eager to report back to their administration, organize and enlist their colleagues
2. Based on limited resources to start new curricula, a majority of the participants are starting with incremental steps such as offering a model course or implementing computational science in a single discipline. There was a definite interest to explore consortial approaches in more depth including how such an approach could be funded.  
3. Participants are interested in follow up assistance in the form of external review and consulting. These can be provided through the XSEDE education program.
4. Across institutions the training needs varied depending on who attended. The training identified in the survey was aligned with the discipline that would be the first on campus to implement. For example, if the engineering or computer science was the lead then training identified included “Parallel Programming” whereas if it was chemistry the training identified was computational chemistry. Participants will be informed of ongoing summer workshop opportunities provided by XSEDE as a way of meeting some of these needs.

Recommendations

Follow up with the participants is in progress to determine if they are continuing to make progress. Completion of the plans and implementation of new curriculum may involve obtaining outside funding to support release time. We recommend that a spring workshop be convened to more deeply explore the consortial arrangements including developing a funding strategy and to review status of the efforts of the initial participating institutions.